Meson-Meson and Meson-Baryon Interactions in Lattice QCD

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Introduction

- *Hierarchical structure in hadron physics*
  (commonly appear in physics…)
  - **quarks / gluons**

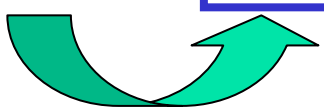
    ➔ [QCD] ➔ hadrons (mesons / baryons)

    ➔ [Nuclear potential] ➔ nucleus, nuclear matter

Fundamental theory

Semi-fundamental theory

(known only phenomenologically)



- How can we understand the interaction between hadrons from the fundamental theory, QCD ?

Introduction

- **We employ lattice QCD**
  - Direct calculation from QCD, no model assumption
  - Nonperturbative framework

Lattice QCD succeeded !

- **quarks / gluons → hadrons → nucleus**

Short distance ←→QCD

  - Meson-meson, meson-baryon interactions
    - What kind of short range interaction appear ? Color-magnetic int. ?
    - Useful for study of multi quark physics, exotics ?
  - Nuclear force between baryons → *next talk by Takahashi*

Formalism

- **Measure the energy of two hadron states and observe the shift of energy from the potential**

$$\Pi_{BM} = \langle J_B(\vec{x},t) J_M(\vec{y},t) \bar{J}_B(\vec{x},0) J_M^{\dagger}(\vec{y},0) \rangle \simeq \lambda_B^2 \lambda_M^2 \exp(-M_{MB} t)$$

$$\Pi_B = \langle J_B(t) \bar{J}_B(0) \rangle \simeq \lambda_B^2 \exp(-M_B t)$$

$$\Pi_M = \langle J_M(t) \bar{J}_M(0) \rangle \simeq \lambda_M^2 \exp(-M_M t)$$

$$\Delta M = M_{BM} - M_B - M_M$$

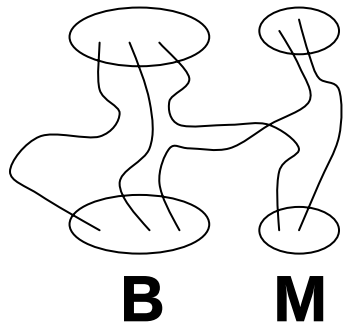
- **Focus the energy difference ΔM to improve S/N**

$$R_{BM} = < \Pi_{BM} > / [< \Pi_B >< \Pi_M >] \simeq \exp(-\Delta M_{BM})$$

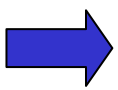
$$R_{MM} = < \Pi_{MM} > / [< \Pi_M >< \Pi_M >] \simeq \exp(-\Delta M_{MM})$$

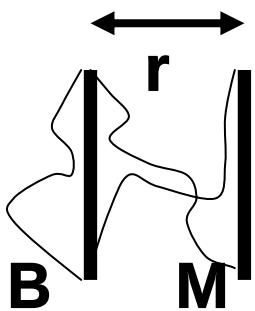
Formalism

- **Potential: V(r)**
- **How can we define the distance "r" between two hadrons ?**



- **➔ adopt one static (heavy) quark in each hadron**
  - **Dynamics of quark propagation can be accessed from other light quarks**





C.Michael, P.Pennanen PRD60(1999)054012

M.S..Cook, H.R.Fiebig hep-lat/0509025

c.f. all quarks are static

F.Okiharu, H.Suganuma, T.T.Takahashi PRL94(2005)192001

Propagator and Diagrams

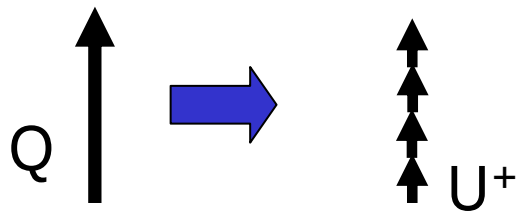
- Operator $J_M = \bar{Q} i\gamma_5 q^3$

  $J_B = \epsilon_{abc}(q_a^{1T} C\gamma_5 q_b^2) Q_c$

  Q: heavy (static) quark

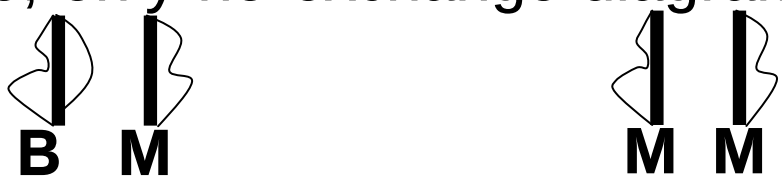
  q: light quark

Note: propagator of static quark can be written by links



- If $q^3 = q^1$ (or q^2) in flavor space, the correlation function includes exchange diagram

- Otherwise, only no-exchange diagram contributes

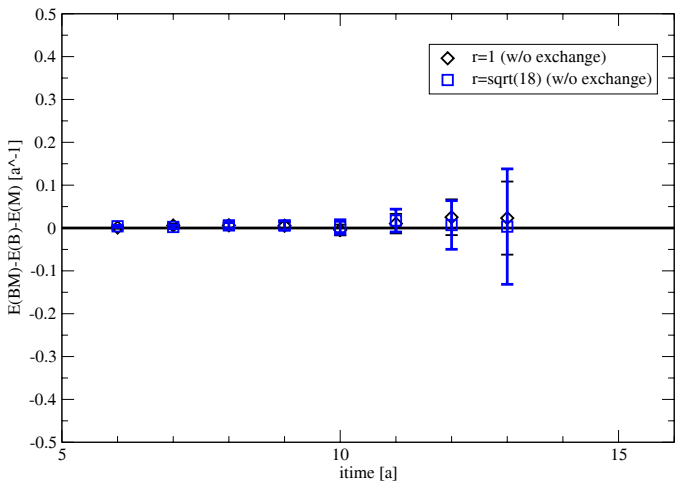


Lattice QCD parameters

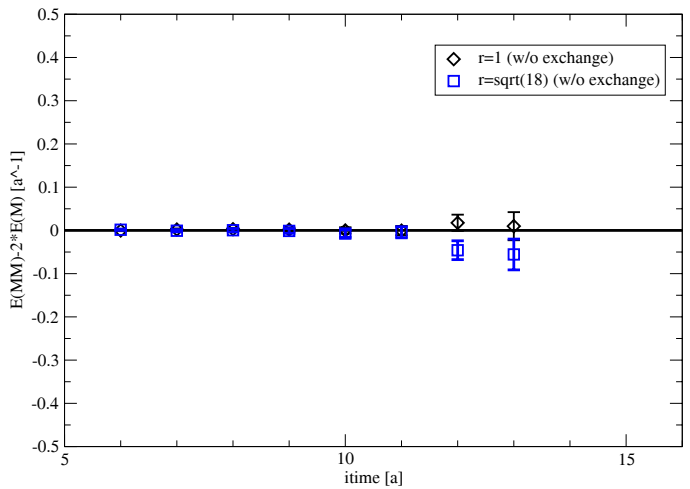
- **Gauge Configurations**
  - Standard Wilson plaquette action
  - β=5.7 → a^{-1}=1.1GeV
  - **$V = 20^3 \times 24$ → $(3.7\text{fm})^3 \times 4.4\text{fm}$**
    - **Large volume to analyze multi hadrons**
  - #(gauge config) =~ 200 configs
- **Fermion action**
  - Wilson fermion at the quenched level
  - κ=0.1600, 0.1625, 0.1650 → mπ= 500-700MeV
  - Average over 2-4 spacial configurations are taken in order to enhance the statistics

Numerical Results: Effective mass plot of R_{BM},R_{MM}

Baryon-Meson



Meson-Meson



Very weak interaction regardless of distance "r"

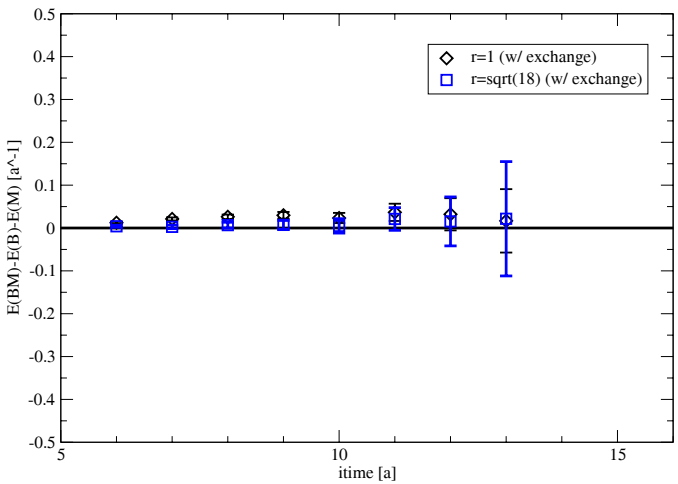
r=0.18fm & 0.78fm

Without exchange diagrams

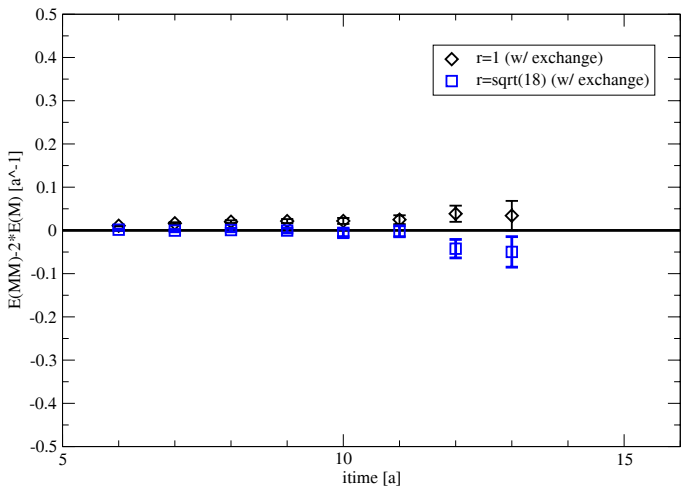
$$R_{BM} = < \Pi_{BM} > / [< \Pi_B >< \Pi_M >] \simeq \exp(-\Delta M_{BM}) \text{ etc.}$$

Numerical Results: Effective mass plot of R_{BM},R_{MM}

Baryon-Meson



Meson-Meson



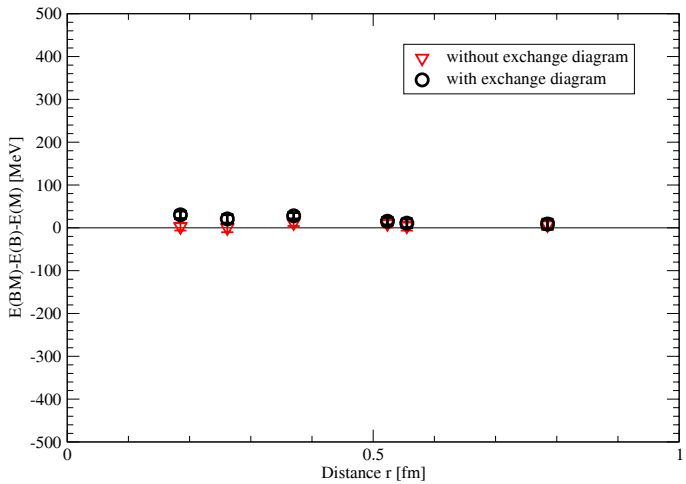
r=0.18fm & 0.78fm

With exchange diagrams

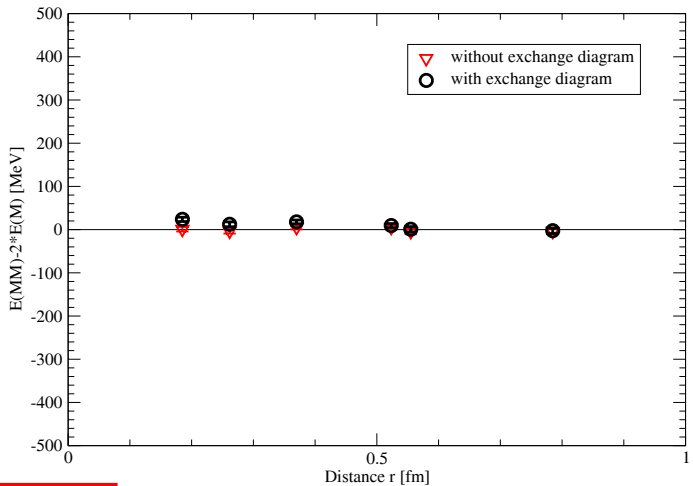
Very weak interaction regardless of distance "r" even when w/ exchange diagram

Potential between two hadrons

Baryon-Meson



Meson-Meson



Interaction is very weak for both of baryon-meson and meson-meson.

Preliminary

Dependence on the quark mass is also weak

Nontrivial feature of heavy-light hadrons ?

Summary

- **We have investigated the meson-meson and meson-baryon interactions from lattice QCD**
  - Define the distance between two hadrons adopting heavy (static) quark in each hadron
  - Correlators with & w/o exchange diagram have been analyzed
  - Large Volume simulation with $V=(3.7\text{fm})^3 \times 4.4\text{fm}$
- **We have not observed significant interaction for both of meson-meson and meson-baryon**
  - Including/Excluding the exchange diagram yields very small effects
  - Does this feature stem from the adopting the heavy quark ?
    - Evaluation of lattice artifact is in progress
  - Is this feature specific only meson-meson & meson-baryon ?
    - ➔ Analysis for baryon-baryon interaction ➔ *next talk*